

Naval Health Research Center

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S. Makeig

D. F. Neri

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NAVAL HEALTH RESEARCH CENTER
P.O. BOX 85122
SAN DIEGO, CALIFORNIA 92186-5122

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A Proposal for Integrated Shipboard Alertness Management

Scott Makeig (*Ph.D.*)

and

David F. Neri (*LCDR, MSC, USN*)

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Human Performance Department
Naval Health Research Center
P.O. Box 85122
San Diego CA 92186-5122
Phone Number: (619) 553-8416
FAX Number: (619) 553-9389
Email: scott@cpl_mmag.nhrc.navy.mil
www: <http://128.49.52.9/~scott>

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Abstract

Under reduced manning policies now proposed for U.S. military naval vessels, continuity of on-duty crew alertness may become a major problem. We propose an integrated hardware and software system for fatigue and alertness management of military shipboard personnel, which would involve: (1) continuous, noninvasive monitoring of crew sleep history via wristband activity monitor; (2) dynamic work/rest scheduling software for optimizing crew schedules under changing missions and personnel demands; (3) real time, objective alertness monitoring of on-duty crew in key work stations using electroencephalographic (EEG) signals recorded via noninvasive dry electrodes built into a cap or audio headset. The system would allow commanders to make operational decisions based on objective knowledge of their crew's state of fatigue and alertness, to maximize human-system efficiency and safety.

Opportunity

High-profile efforts are now being made by the U.S. Navy to evaluate new paradigm-breaking technology to help implement reduced manning of future and/or currently-operating Navy ships. The strategic importance to the Navy of maintaining a combat-ready fleet with a shrinking personnel base is high enough that it may be willing to reevaluate current watchstanding traditions and entertain new concepts based on advancing scientific knowledge of fatigue and circadian rhythms. Some current work/rest schedules on board surface ships and submarines appear to be at odds with basic facts of circadian physiology. For example, many submarine enlisted crew members must endure an 18-hour work/rest cycle during deployments (see Kelly & Neri, this volume), even though it has been known for many years that the human circadian system is unable to adapt to cycle lengths outside of a range of 21-28 hours (Czeisler, Allan, & Kronauer, 1990). A likely consequence of working under a contracircadian work/rest schedule is increased variability in cognitive performance, since under contracircadian conditions, work periods and periods of peak mental/physical performance coincide only infrequently.

Shipboard Work/Rest Scheduling

Navy work/rest scheduling practices have developed over centuries of grappling with a difficult logistical problem. Navy ships must be operated around the clock, and require constant attention by crew members with many different kinds of training. Ship missions change frequently, and often involve progressive time zone changes that produce desynchrony between physiological (circadian rhythms) and the dark/light cycle. Light is now known to be the most powerful *zeitgeber* or synchronizing influence on the human circadian system (Czeisler, 1995).

A key challenge for commanders of Navy ships operating under reduced manning will be the necessity of maintaining continuous crew alertness under frequently-changing operating conditions in an enclosed environment. Currently, ship commanders rely on rules of thumb and their years of experience to decide when their crew is insufficiently rested, and to adjust the ship's official readiness level accordingly. In individual duty stations, such as air defense, section chiefs personally monitor their on-duty crewmen, replacing them with waiting reserves when they detect one of them has become drowsy. Individual crewmen, meanwhile, are reprimanded for dozing off on the job, and rely on "gallons and gallons" of coffee, as one sonarman put it, to remain sufficiently alert to avoid reprimands. However, the alertness of the section chiefs is not necessarily monitored, and their abilities to detect alertness problems in their crew before serious vigilance or judgment lapses occur are untested.

Crew problems in maintaining alertness may be greatly exacerbated under reduced manning, when extra personnel will not be available for on-line crew monitoring and unscheduled replacements. Of course, the problem of managing alertness in around-the-clock transportation-related work environments is not unique to the Navy. For example, a sizable number of commercial maritime industry attendees to the recent National Transportation Safety Board (NTSB) workshop on Managing Fatigue in Transportation (November, 1995) recounted ongoing difficulties in maintaining safety, performance, and crew well-being during continuous

operations. Anecdotal stories of accidents that might have happened abound among circadian researchers -- commercial airline crews overflying Los Angeles, bus drivers and ship pilots asleep at the wheel.

Unfortunately, in both commercial and military transportation organizations, such stories rarely reach official ears in time for a full inquiry until a disaster refocuses official attention on the difficulty of maintaining crew alertness during around-the-clock operations. Under normal conditions, management may adopt a "right-stuff" attitude, maintaining their personnel should be counted on under any circumstance, and may rely comfortably on long-held operating traditions to maintain optimum performance under changing circumstances. Attitudes within the military toward workplace fatigue may not be far from those held by commercial managers or the public at large.

At the recent NTSB meeting, Professor William Dement recounted a story illustrative of the little regard given to alertness problems by society as a whole. He recalled that 20 years ago, when some drunk university students crashed their car into his yard, they were given a wink and a nod by the investigating authorities. Today, drunk drivers are much more severely punished for their irresponsibility. Yet when recently a sleepy student missed the same curve one early morning, Professor Dement noted he was again treated sympathetically by the arriving police. This student most probably knew he was driving with impaired alertness as much as drunk drivers know they are impaired. However, our society has not yet appreciated and accepted the importance of responsible alertness management, even where public safety is involved.

As the world's largest shiftwork employer (U.S. Congress, 1990), the U.S. Navy stands to suffer the most severe consequences of reduced crew alertness under reduced manning conditions. However, behavioral and physiological science has progressed to the point where more responsible and scientific methods of alertness management are not only conceivable, but possible, and are becoming increasingly important.

An Integrated Fatigue Management System

For several years, the first author and colleagues at the Naval Health Research Center, San Diego have been working to design and test an objective alertness monitoring system based on EEG spectral information derived from dry electrodes mounted on an audio headset or cap (Makeig, Elliott, Inlow & Kobus, 1990; Makeig & Inlow, 1993; Makeig, Elliott & Postal, 1993; Makeig & Jung, 1995; Makeig & Jung, in press; Makeig, Jung & Sejnwoiski, in press; Makeig, Bell, Jung & Sejnowski, in press), and the second author has been investigating both nonpharmacological and pharmacological countermeasures to alertness and performance degradation due to sustained operations and sleep loss. Here, however, we would like to take the opportunity to present a wider view, and suggest that managing crew alertness, particularly under reduced manning, should best be accomplished using an integrated three-pronged system which includes:

- (1) Continuous monitoring of crew wake/sleep history and light exposure.
- (2) Continuous dynamic crew work/rest scheduling based on a current fatigue model.
- (3) Objective alertness monitoring of on-duty crew in key work stations.

We therefore propose a system in which the work/rest schedules of the crew members would be dynamically programmed and maintained using advanced software for dynamic work/rest scheduling (DWRS) based on individualized crew:

- (1) Sleep/wake history (wake/sleep period times and durations)
- (2) Light exposure history (strong/dim light exposure times and durations)
- (3) Tasking and training (by individual or duty section)
- (4) Projected ship tasking (direction, rate of travel, etc.)

Crew sleep records would be continuously updated from advanced wrist actigraph measurements (Belenky, this volume). Activity and light exposure data would be broadcast continuously to receivers embedded in the ship crew living and work spaces. Objective alertness

monitoring of on-duty personnel in key duty stations would be accomplished using a dry electrode EEG and eye-movement based alertness monitoring/management (AMM) system. DWRS software would help manage crew alertness in several ways:

- (1) When the central DWRS software detected that estimated current fatigue levels and projected ship tasking were incompatible, the DWRS system would advise the Commanding Officer to review scheduled ship tasking and/or institute further countermeasures (e.g., medication).
- (2) When DWRS software detected that an individual crew member's sleep record was incompatible with sustained alertness, it might suggest remedies including scheduling extra rest and/or medical intervention.
- (3) When alertness lapses were detected in on-duty crew by the real-time alertness monitoring system, there would be multiple levels of response intervention:
 - (a) The system could deliver immediate feedback to the operators to help them be aware of and better manage their own alertness.
 - (b) The system could adjust the rate and/or pattern of information presentation to the operator, or redistribute the information load among operators, to maintain overall human-system performance.
 - (c) The system could search the sleep-history database for a better-rested replacement operator.
 - (d) The system could reprogram the ship's planned work/rest schedule to incorporate:
 - (i) Extra rest for the affected operator;
 - (ii) Extra rest for the replacement operator, and, if necessary;
 - (iii) Extra rest for any further schedule adjustments needed to fill the replacement operator's previous tasking.
 - (e) When no replacement was available and simple feedback to the operator did not improve their alertness, the system might suggest further alertness management interventions (e.g., light exposure, drugs).

(4) Carefully programmed bright light exposure can synchronize biological circadian rhythms under conditions of shifting time zones and/or work schedules (Czeisler, 1995). The DWRS system could also control individualized lighting in crew berthing spaces, producing synthetic "sunrises" and "sunsets" to help crew members adjust to necessary work/rest schedule shifts, including time-zone shifts.

Prospects and Potential

Is this proposal only a futuristic vision? We believe much of the integrated alertness management system we outline here could be demonstrated, at least in outline, in the very near term. Promotion and execution of a demonstration project would require high-level Navy support and development of active collaborations between basic, clinical, and applied military and academic researchers. The alertness model at the heart of the system would require gradual refinement based on continuing laboratory and applied research. Practical real-time alertness monitoring will require one or more stages of advanced development before it is fully ready for routine implementation. Producing convenient and effective software for dynamic work/rest scheduling will be a challenge for database programmers. The proposed changes in work/rest scheduling and real-time alertness monitoring might well be complemented by parallel efforts to identify and reduce boredom in monitoring tasks using intelligent work scheduling software to control the rate and flow of operator work load.

Benefits of the proposed system would be an optimally-rested, better- and more safely-performing crew, and more exact information for ship officers about their crew's current psychobiological capabilities. These benefits could greatly increase the effectiveness of Navy ships operating under reduced manning. Our current efforts at the Naval Health Research Center to develop objective alertness monitoring technology and to document performance effects of contracircadian work/rest schedules are ongoing. Hopefully, the proposal presented here may

serve to draw readers' attention to the importance of work/rest and alertness issues to the ultimate success of Navy reduced-manning efforts, and to introduce a vision of a truly integrated alertness/fatigue ship management system to support Navy crew to remain "the best they can be."

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